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# Irregular Snow Crystals: Structural Features as Revealed by Low Temperature Scanning Electron Microscopy

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**Summary:** For nearly 50 years, investigators using light microscopy have vaguely alluded to a unique type of snow crystal that has become known as an irregular snow crystal. However, the limited resolution and depth-of-field of the light microscope has prevented investigators from characterizing these crystals. In this study, a field-emission scanning electron microscope, equipped with a cold stage, was used to document the structural features, physical associations, and atmospheric metamorphosis of irregular snow crystals. The crystals appear as irregular hexagons, measuring 60 to 90 mm across, when viewed from the a-axis. Their length (c-axis) rarely exceeds the diameter. The irregular crystals are occasionally found as secondary particles on other larger forms of snow crystals; however, they most frequently occur in aggregates consisting of more than 100 irregular crystals. In the aggregates, the irregular crystals have their axes oriented parallel to one another and, collectively, tend to form columnar structures. Occasionally, these columnar structures exhibit rounded faces along one side, suggesting atmospheric metamorphoses during formation and descent. In extreme cases of metamorphoses, the aggregates would be difficult to distinguish from graupel. Frost, consisting of irregular crystals, has also been encountered, suggesting that atmospheric conditions that favor their growth can also occur terrestrially.

**Key words:** field-emission scanning electron microscopy, low-temperature scanning electron microscopy, snow crystals, irregular crystals, snowflakes, rime, graupel

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## Introduction

Snow crystals have been studied with the light microscope for more than 100 years. However, because of their small size, delicate structure, and topography, this instrument has failed to elucidate many of the structural details of the crystals. In addition, snow is difficult to transport, store, image, and photograph without subjecting samples to structural changes resulting from sublimation, melting or recrystallization. Examination of snow crystals with a scanning electron microscope (SEM) would solve problems associated with resolution, topography, and their delicate nature. However, for obvious reasons, frozen samples cannot be imaged at ambient temperatures in a conventional SEM.

In 1970, Echlin *et al.* (1970) solved this problem for biologists by describing a cold stage that could be interfaced with an SEM and operated at temperatures below –130° C. At these temperatures, the vapor pressure of water is not significant and sublimation does not occur at a detectable rate. Furthermore, recrystallization of pure water-ice does not occur (Beckett and Read 1986) and frozen, fully hydrated samples remain stable for several hours while being observed (Wergin and Erbe 1991).

Recently, this procedure, which has become known as low-temperature (LT) SEM, was used to compare frozen, fully hydrated, fractured membranes of yeast in the SEM with the platinum/carbon (Pt/C) replicas of the identical cells in the transmission electron microscope (TEM) (Wergin and Erbe 1990). Results indicated that macromolecular particles, as small as 10 nm in diameter, retained their structure, were stable, and could be imaged and photographed with LTSEM. The images, which were obtained in the LTSEM, were comparable with those of the same cells in the Pt/C replicas, which were photographed in a TEM. Encouraged by these results, identical snow crystals were imaged and photographed with a light microscope, imaged and photographed in the

LTSEM, and then rephotographed with a light microscope. The results further demonstrated that observation in the LTSEM did not alter the structure of the snow crystals (Wergin *et al.* 1998). In addition, techniques were developed to collect, ship, and store fresh and metamorphosed snow crystals for subsequent imaging with an LTSEM. These techniques have been successfully used to record detailed images of thousands of snow crystals that were collected from numerous states including Alaska, Colorado, Montana, Utah, Wyoming, Wisconsin, Maryland, and West Virginia. In previous studies, we have described the detailed structure of snow and ice grains including columns, needles, plates, stellar dendrites, depth hoar, and glacial ice that were collected from several states (Rango *et al.* 1996a, b, 2000; Wergin and Erbe 1994a, b; Wergin *et al.* 1995, 1996a, b, 1998, 1999). The current study uses LTSEM to illustrate the features and distinctive characteristics of the elusive group of crystals recognized by The International Commission on Snow and Ice (Colbeck *et al.* 1990) and simply referred to as "irregular crystals."

## Materials and Methods

### Collection Procedure

Data illustrated in this study resulted from six different snow collections during 1993–1999 from sites near the following locations: Beltsville, Maryland; Bearden Mt., West Virginia and Greenwood, Wisconsin. The samples, which were obtained when the air temperatures ranged from –5°C to 0°C, consisted of freshly fallen snowflakes. To collect samples, a thin layer of liquid Tissue-Tek, a commonly used cryoadhesive for biological samples, was spread on a flat copper plate (15 × 27 mm). The Tissue-Tek and the plates were precooled to ambient outdoor temperatures (below freezing) before use. Newly fallen snowflakes were either permitted to settle on the surface of the Tissue-Tek or were lightly dislodged from the snow surface and allowed to fall onto the surface of the cryoadhesive. Next, the plate was either rapidly plunged into a Styrofoam vessel containing liquid nitrogen ($LN_2$) or placed on a brass block that had been precooled with $LN_2$ to –196°C. This process, which solidified the Tissue-Tek, resulted in firmly attaching the snow crystals to the plate. The frozen plates were inserted diagonally into prefabricated 20 cm segments of square, brass channel tubing, containing an end cap, and lowered into dry shipping dewars that had been previously cooled with $LN_2$. The dewars containing the samples were conveyed from the collection sites and then either transported by van (from West Virginia) or shipped by air (Wisconsin) to the laboratory in Beltsville, Maryland. Upon reaching the laboratory, the samples were transferred under $LN_2$ to a $LN_2$ storage dewar where they remained at –196°C for as long as 9 months before being further prepared for observation with LTSEM.

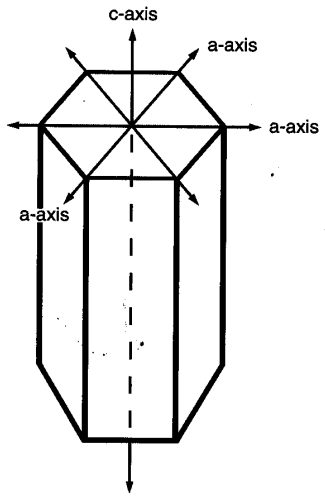


FIG. 1 Diagram illustrating the crystallographic axes of snow crystal growth. Environmental conditions that favor growth along the a-axes result in flat hexagonal plates and stellar dendrites, whereas conditions that favor c-axis growth produce elongated columns and needles. Neither type of growth predominates in the formation of irregular crystals.

## Conclusion

This study uses LTSEM to characterize small discrete crystals believed to correspond to the irregular crystals that previous investigators have attempted to describe with the light microscope. These crystals, which appear as irregular hexagons when viewed along their a-axes, generally measure 60 to 90 μm across. Their lengths (c-axis) rarely exceed their diameters. Although the irregular crystals are occasionally found as individual, secondary particles on other larger forms of snow crystals, such as plates and dendrites, they are most frequently encountered in aggregates consisting of more than 100 crystals that tend to form a column. The aggregates are often associated with needles, suggesting that the atmospheric conditions that favor needle growth may be close to those that favor growth of irregular crystals. Furthermore, examples believed to represent atmospheric metamorphoses of irregular crystals are commonly encountered. Metamorphosis can result in aggregates that consist of partially sublimated crystals and droplets that collectively would be difficult to distinguish from graupel when using a light microscope.